Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 81 (2014) 1547 – 1552

Procedia Engineering

www.elsevier.com/locate/procedia

11th International Conference on Technology of Plasticity, ICTP 2014, 19-24 October 2014, Nagoya Congress Center, Nagoya, Japan

Effect of casting parameters on roll separation force during twin roll casting

Yun-Soo Lee, Hyoung-Wook Kim, Jae-Hyung Cho*

Light Metals Division, Korea Institute of Materials Science, Changwon 642-831, Korea

Abstract

A two-dimensional finite element analysis was adopted to predict temperature distribution and roll separation force during twin roll casting of A7075 aluminum alloy strip. The influence of various parameters such as roll speed, initial temperature of the melt and heat transfer coefficient on temperature distribution and roll separation force was investigated in detail. The results were useful to comprehensively understand the casting process and to effectively reduce the experimental trial-and-error procedures of twin roll casting process.

Keywords: Aluminum alloys; Twin roll casting; Simulation; Roll separation force

1. Introduction

Aluminum alloys have attracted much attention for the automotive industry due to their significant advantages such as weight reduction related with fuel efficiency [1]. However, it is difficult to fabricate high strength aluminum sheets by conventional process based on direct-chill casting because of its numerous post-processes. As a result, the high strength aluminum alloy sheets from conventional process are more expensive than steel, therefore, it has prevented their widespread applications in automotive industry.

* Corresponding author. Tel.: +82-55-280-3306; fax: +82-55-280-3299.
E-mail address: jhcho@kims.re.kr

doi:10.1016/j.proeng.2014.10.188

One of the techniques for solving this problem is twin roll casting process. The twin roll casting is regarded as the most prospective technique to fabricate near-net-shape casting strips. It is also well known as an economic process to make aluminum alloy strips because one-step processing from melt to wrought strip by combining casting and hot rolling process considerably reduces cost and time [2]. Moreover, it is possible to obtain refined solidification microstructure and fine secondary particles by high cooling rate, which is closely related to the mechanical properties [3]. This process, however, has to be performed within a narrow working window in order to avoid defects that cause expensive trial-and-error cost and time. The twin roll casting is an integrated process, and it is necessary to control numerous parameters in a narrow solidification range from the nozzle tip to the roll nip such as melt temperature, melt feeding rate, casting speed, nozzle shape, roll gap, amount of coolant and so on [4]. Therefore, modeling and simulation techniques for optimizing processing conditions are very helpful to reduce experimental trial-and-error procedures.

In the present study, a commercial finite element code, DEFORM was applied to simulate both temperature distribution and roll separation force during twin roll casting process of A7075 aluminum alloy strip. The influence of simulation parameters such as roll speed, melt temperature and heat transfer coefficient on temperature distribution and roll separation force was discussed in detail.

Nomenclature

R_{inner}	Inner radius of the roll (mm)
R_{outer}	Outer radius of the roll (mm)
L	Distance between the nozzle tip and roll nip (mm)
d	Thickness of solidified strip (mm)
k_{roll}	Thermal conductivity of roll (W/m·K)
$C_{p\text{roll}}$	Specific heat of roll (J/kg·K)
v	Roll speed (rpm)
$m_{\text{roll-strip}}$	Friction coefficient between roll and strip
T_{roll}	Initial temperature of roll (K)
T_{melt}	Initial temperature of melt (K)
T_{coolant}	Temperature of coolant (K)
$T_{\text{atmosphere}}$	Temperature of atmosphere (K)
$h_{\text{roll-strip}}$	Heat transfer coefficient between the roll and the strip (W/m^2·K)
$h_{\text{roll-coolant}}$	Heat transfer coefficient between the roll and the coolant (W/m^2·K)
$h_{\text{strip-atmosphere}}$	Heat transfer coefficient between the strip and the atmosphere (W/m^2·K)
$h_{\text{roll-atmosphere}}$	Heat transfer coefficient between the roll and the atmosphere (W/m^2·K)

2. Finite element model for twin roll casting process

A two-dimensional schematic representation of the horizontal twin roll strip caster is illustrated in Fig. 1. During twin roll casting process, irregular melt flow such as reverse flow or vortex can occur and affect the temperature distribution of the strip [5]. We simply assumed that melt smoothly moves inside the nozzle with minimized irregular flow. In addition, the width of the strip was generally large compared to the thickness of the strip, and the geometry of the modelling was approximated as two-dimension neglecting the end effect of the strip. The mechanical properties at elevated temperatures and various deformation rates of A7075 aluminum alloy were obtained from the DEFORM materials library. Thermal properties depending on temperature computed from JMatPro software were presented in Fig. 2. The simulations were carried out on twin roll casting of A7075 aluminum alloy strips with a thickness of 4 mm considering various roll speeds (v = 3, 4, 5 rpm), initial melt temperatures (T_{melt} = 933, 943, 953 K) and heat transfer coefficients between casting roll and coolant ($h_{\text{roll-coolant}}$ = 5,000, 8,000, 10,000 W/m^2·K). The detailed design and casting parameters are summarized in Table 1.

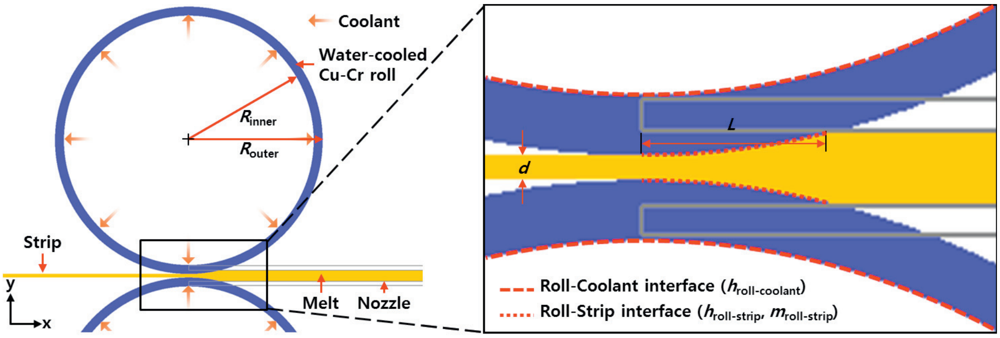

Fig. 1. Schematic representation of horizontal twin roll casting process.

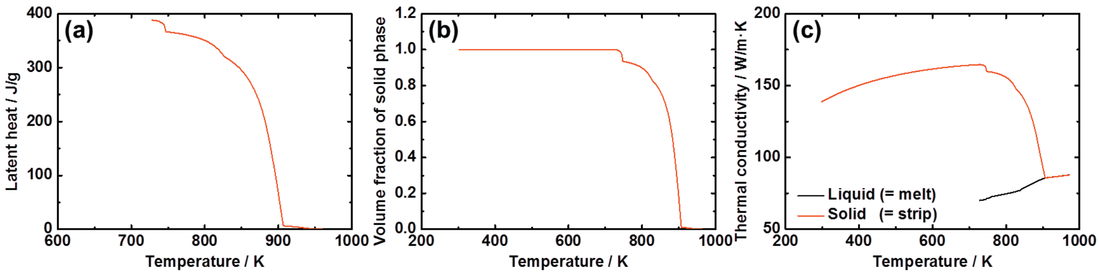

Fig. 2. Thermal properties of A7075 aluminum alloys used for simulations (JMatPro): (a) latent heat, (b) volume fraction of solid phase, and (c) thermal conductivity.

Table 1. Model dimension and casting parameters for simulation running.

Symbol	Value	Symbol	Value
R_{inner}	140 mm	T_{roll}	373 K
R_{outer}	150 mm	T_{melt}	933, 943, 953 K
L	35 mm	$T_{coolant}$	293 K
d	4 mm	$T_{atmosphere}$	293 K
k_{roll}	324 W/m·K	$h_{roll\text{-}strip}$	7,000 W/m^2·K
C_{Proll}	385 J/kg·K	$h_{roll\text{-}coolant}$	5,000, 8,000, 10,000 W/m^2·K
v	3, 4, 5 rpm	$h_{strip\text{-}atmosphere}$	20 W/m^2·K
$m_{roll\text{-}strip}$	1	$h_{roll\text{-}atmosphere}$	20 W/m^2·K

3. Results and discussion

When twin roll casting process begins, the melt moves into the roll nip through the nozzle. Right after contacting the roll surface, solidification of the melt proceeds from the outer surfaces of the strip contacting to the rolls towards the centreline, and the temperature of the casting rolls became stable as shown in Fig. 3. At the initial stage of twin roll casting, the temperature of the casting rolls increased from the nozzle tip to vicinity of roll nip because of melt contact as shown in Fig. 3(a). After few seconds, the roll temperature gradually decreased by recirculating coolant inside the roll as shown in Fig. 3(b). In 15 seconds, the roll temperature enters into a near-stable state as shown in Fig. 3(c) and (d). Accordingly, the roll separation force rapidly changes at the beginning of twin roll casting by solidification, then gradually stabilized with casting time.

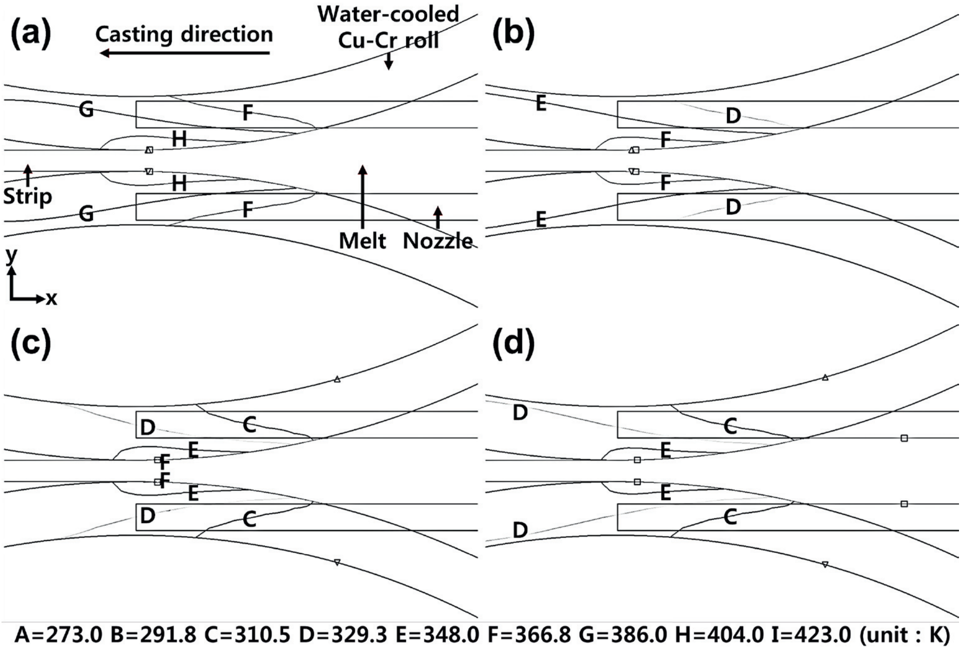

Fig. 3. Temperature distributions of water-cooled Cu-Cr rolls at v = 5 rpm, T_{melt} = 953 K and $h_{roll\text{-}coolant}$ = 10,000 W/m^2·K during simulation running: (a) 1 sec, (b) 5 sec, (c) 15 sec, (d) 25 sec.

3.1. Influence of roll speed, v on roll separation force

Various effects of roll speed (v), initial melt temperature (T_{melt}) and heat transfer coefficient between the roll and the coolant ($h_{roll\text{-}coolant}$) on roll separation force are presented in this study. In the current section, influence of roll speed on roll separation force is discussed. Roll speed, v is one of the dominant factor to affect temperature distribution and roll separation force as shown in Fig. 4. The T_{melt} and $h_{roll\text{-}coolant}$ were kept constant at 953 K and 10,000 W/m^2·K, respectively. The contours of high temperature and liquid fraction move to the roll nip with increase in v, as described in Fig. 4(a) and (b), respectively. As the v increases, heat loss through the casting rolls decreases by short contact time. This results in a small amount of solid fraction or thin solid shell at the beginning of solid strip formation. Also, the v affected roll separation force as shown in Fig. 4(c). The roll separation force gradually decreased from 25 to 9 tons with increasing v from 3 to 5 rpm, approximately [6].

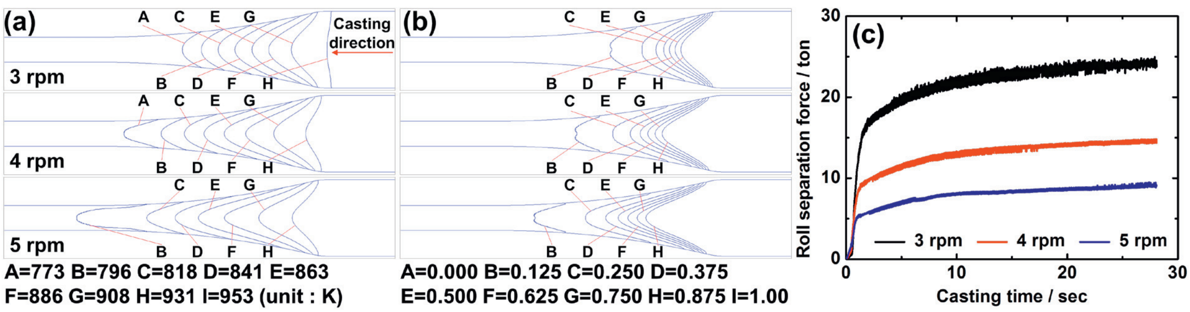

Fig. 4. Effect of roll speed, v on distribution of (a) temperature, (b) liquid fraction and (c) roll separation force at T_{melt} = 953 K and $h_{roll\text{-}coolant}$ = 10,000 W/m^2·K.

3.2. Influence of melt temperature, T_{melt} on roll separation force

Initial temperature of the melt, T_{melt} contributes to the temperature distribution of the strips and roll separation force. When other parameters were assumed to be constant, effect of the T_{melt} on the solidification profiles was investigated. The high T_{melt} causes severe surface oxidation by high temperature at the strip exit, and thus the T_{melt} should be as low as possible [7]. On the other hand, the low temperature of the melt pulls back the overall location of the mushy zone to the melt. This increases roll separation force and frequently stops the casting process. Distributions of temperature, liquid fraction and roll separation force were obtained according to various T_{melt} from 933 to 953 K as shown in Fig. 5. The v and $h_{\mathrm{roll\text{-}coolant}}$ were kept constant at 5 rpm and 10,000 W/m^2·K, respectively. The temperature of the strip below the roll increased with increase in T_{melt} as shown in Fig. 5(a). The mushy zone at 953 K was greater than that at 933 K as shown in Fig. 5(b). It shows a similar trend to the cases of v variation mentioned above. The roll separation force gradually decreased from 12.5 to 8 tons with increasing T_{melt} from 933 to 953 K.

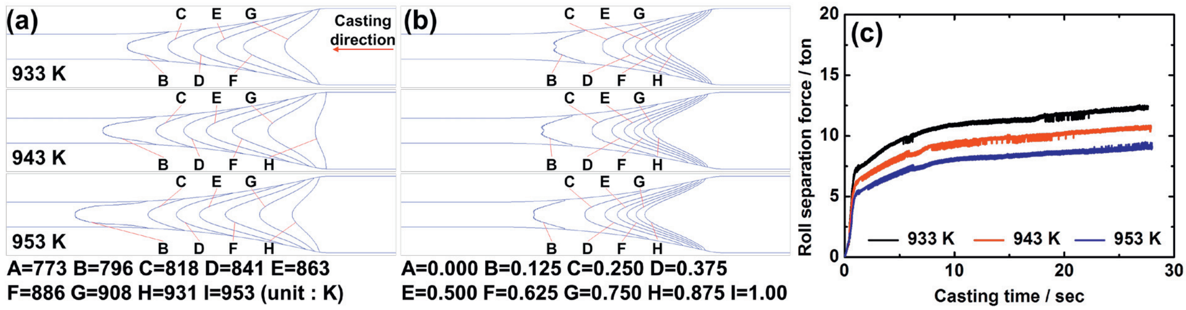

Fig. 5. Effect of melt temperature, T_{melt} on distribution of (a) temperature, (b) liquid fraction and (c) roll separation force at $v = 5$ rpm and $h_{\mathrm{roll\text{-}coolant}} = 10{,}000$ W/m^2·K.

3.3. Influence of heat transfer coefficient, $h_{roll\text{-}coolant}$ on roll separation force

Heat transfer coefficient between roll and coolant, $h_{\mathrm{roll\text{-}coolant}}$ also influences on the temperature distribution and roll separation force. Distributions of temperature, liquid fraction and roll separation force were obtained according to change of the $h_{\mathrm{roll\text{-}coolant}}$ from 5,000 to 10,000 W/m^2·K as shown in Fig. 6. The $h_{\mathrm{roll\text{-}coolant}}$ can be controlled by changing temperature or flow rate of coolant. The v and T_{melt} were kept constant at 5 rpm and 953 K for all cases, respectively. The influence of the $h_{\mathrm{roll\text{-}coolant}}$ on temperature distribution, liquid fraction and roll separation force were relatively small compared with that of v and T_{melt} as shown in Fig. 6(a), (b) and (c), respectively. These results show that the effect of $h_{\mathrm{roll\text{-}coolant}}$ is negligibly small during short contact time of casting rolls and strip.

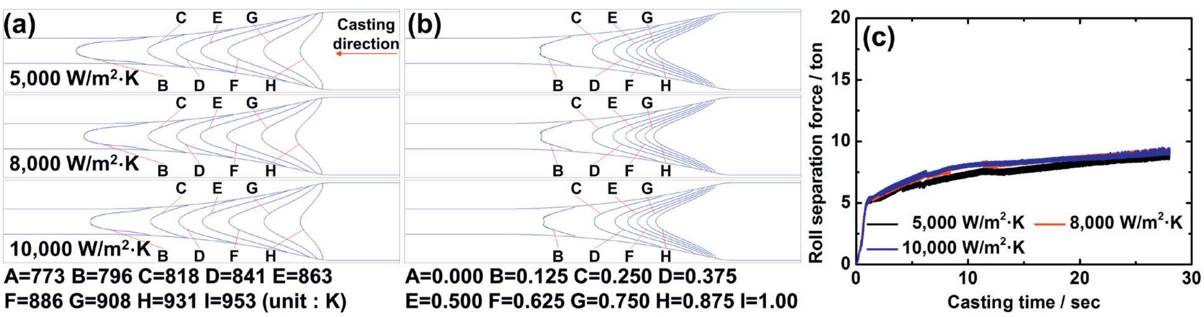

Fig. 6. Effect of heat transfer coefficient, $h_{\mathrm{roll\text{-}coolant}}$ on distribution of (a) temperature, (b) liquid fraction and (c) roll separation force at $v = 5$ rpm and $T_{\mathrm{melt}} = 953$ K.

4. Summary

A two-dimensional finite elements analysis was carried out to predict the temperature distribution, solid/liquid volume fraction in the mushy zone, and roll separation force during twin roll casting process. The effect of roll speed, melt temperature and heat transfer coefficient between roll and coolant was investigated in detail. The contours of high temperature and liquid fraction move to the roll nip, and roll separation force decreased with increase in roll speed and melt temperature. However, the effect of $h_{\text{roll-coolant}}$ is negligibly small, compared with that of v and T_{melt}.

Acknowledgements

This research was supported by Fundamental Research Program of the Korea Institute of Materials Science (KIMS).

References

[1] Cole, G.S., Sherman, A.M., 1995. Lightweight Materials for Automotive Applications. Materials Characterization 35, 3-9.

[2] Haga, T., Tkahashi, K., Ikawaand, M., Watari, H., 2004. Twin roll casting of aluminum alloy strip. Journal of Materials Processing Technology 153-154, 42-47

[3] Kim, H.-W., Cho, J.-H., Lim, C.-Y., Kang, S.-B., 2010. Microstructure and tensile properties of Al-(5~10)wt%Mg alloy sheets fabricated by twin roll casting and rolling process. Key Engineering Materials 443, 45-50.

[4] Sahoo, S., Kumar, A., Dhindaw, B.K., Ghosh, S., 2012. Modeling and experimental validation of rapid cooling and solidification during high-speed twin-roll strip casting of Al-33 wt pct Cu. Metallurgical and Materials Transactions B:Process Metallurgy and Materials Processing Science 43, 915-924.

[5] Zeng, J. Koitzsch, R., Pfeifer H., Friedrich, B., 2009. Numerical simulation of the twin-roll casting process of magnesium alloy strip, Journal of Materials Processing Technology 209, 2321-2328.

[6] Saxena, A., Sahai, Y., 2002. Modeling of thermo-mechanical stresses in twin-roll casting of aluminum alloys. Materials Transactions 43, 214-221.

[7] Zhang, X.M., Jiang, Z.Y., Yang, L.M., Liu, X.H., Wang, G.D., Tieu, A.K., 2007. Modelling of coupling flow and temperature fields in molten pool during twin-roll strip casting process. Journal of Materials Processing Technology 187-188, 339-343.